VIRGINIA
Route 40, Brookneal

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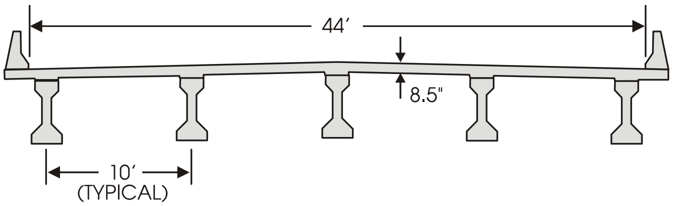
Route 40, Brookneal

1. DESCRIPTION



Location:	Route 40 over Falling River, Brookneal in Lynchburg District
Open to traffic:	May 1996
Environment:	Normal over river
HPC Elements:	Substructure, girders, and deck
Total Length:	320 ft
Skew or Curve:	20^{o} skew, no curve
Girder Type:	AASHTO Type IV
Girder Span Lengths:	Four spans at 80 ft
Girder Spacing:	10 ft
Girder Strand Grade:	270
Girder Strand Dia.:	0.5 in
Max. No. of Bottom Strands:	54 at 2 in c/c
Deck Thickness:	8.5 in
Deck Panels:	None

2. BENEFITS OF HPC AND COSTS

A. Benefits of HPC

The 8000-psi concrete compressive strength in the girders enabled the use of five lines of girders rather than the seven lines that would have been required with a compressive strength of 6000 psi. The total cost of the bridge was $49.32/ft^2 of deck surface. This was lower than the average Federal-aid cost of $58/ft^2 for bridges built that year. Concrete had to meet low permeability requirements, which are expected to result in longer service life with minimal maintenance.

B. Costs

Total Cost: $49.32/ft^2 of deck surface area

3. STRUCTURAL DESIGN

Design Specifications:	AASHTO Standard Specifications for Highway Bridges, 1992
Design Live Loads:	HS 20-44 or military load
Seismic Requirements:	AASHTO Seismic Performance Category A
Flexural Design Method:	AASHTO Standard Specifications 9.17
Maximum Compressive Strain:	0.003
Shear Design Method:	AASHTO Standard Specifications 9.20
Fatigue Design Method:	None
Lateral Stability Considerations:	Diaphragms at midspan and ends
Allowable Tensile Stress	
—Top of Girder at Release:	$3\sqrt{f'_{ci}} = 232$ psi
—Bottom of Girder after Losses:	$3\sqrt{f'_{c}} = 268$ psi
Prestress Loss:	28%
Method Used for Loss:	AASHTO Standard Specifications 9.16.2.1
Calculated Camber:	1.25 in
Concrete Cover	
—Girder:	2 in to strand, 1 in to stirrups
—Top of Deck:	2.75 in to center of the top bar
—Bottom of Deck:	1.5 in to center of the bottom bar
—Other Locations:	Not available
Properties of Reinforcing Steel	
—Girder:	ASTM A 615 Grade 60, epoxy coated
—Deck:	ASTM A 615 Grade 60, epoxy coated
Properties of Strand	
—Grade and Type:	Grade 270, low relaxation
—Supplier:	Not available
—Surface Condition:	Not available
—Pattern:	Draped
—Transfer Length:	50 diameters = 25 in
—Development Length:	1.6 l_d from AASHTO Standard Specifications 9.28

4. SPECIFIED ITEMS

A. Concrete Properties

	Girders	Substructure	Deck
Minimum Cementitious Materials Content:	635 lb/yd^3	588 lb/yd^3	635 lb/yd^3
Max. Water/Cementitious Materials Ratio:	0.32	0.49	0.45
Min. Percentage of Fly Ash:	20	20	20
Max. Percentage of Fly Ash:	25	25	25
Min. Percentage of Silica Fume:	7	7	7
Max. Percentage of Silica Fume:	10	10	10
Min. Percentage of GGBFS:	35	35	35
Max. Percentage of GGBFS:	50	50	50
Maximum Aggregate Size:	1 in	1 in	1 in
Slump:	0-4 in (1)	1-5 in (1)	2-4 in (1)
Air Content:	4.5 $\pm$ 1.5% (2)	6.0 $\pm$ 2% (2)	6.5 $\pm$ 1.5% (2)

Note: Minimum and maximum percentages of mineral admixtures only apply if the materials are used.

	Girders	Substructure	Deck
Compressive Strength			
—Release of Strands:	6000 psi	—	—
—Design:	8000 psi at 28 days	3000 psi at 28 days	4000 psi at 28 days
Chloride Permeability: (AASHTO T 277)	1500 coulombs at 28 days (3)	3500 coulombs at 28 days (3)	2500 coulombs at 28 days (3)
ASR or DEF Prevention:	ASR (4)	ASR (4)	ASR (4)
Freeze-Thaw Resistance:	Not specified	Not specified	Not specified
Deicer Scaling:	Not specified	Not specified	Not specified
Abrasion Resistance:	Not specified	Not specified	Not specified
Other:	—	—	—

(1) Maximum of 7 in when a high-range water-reducing admixture (HRWR) is used.
(2) Target air content is increased by 1 percent when a HRWR is used.
(3) Virginia uses a curing procedure of one week at 73 ^oF and three weeks at 100 ^oF with the AASHTO T 277 test.
(4) Cement shall be Type II with a maximum alkali content of 0.40% or Type I-P, unless otherwise specified in the contract. Fly ash or granulated iron blast-furnace slag shall not be added to concrete when Type I-P cement is used. Fly ash, granulated iron blast-furnace slag, silica fume, or other VDOT approved mineral admixtures shall be used with Types I, II (if above 0.40% alkali content), or III cements.

B. Specified QC Procedures

Girder Production	
Curing:	Steam or moist
Internal Concrete Temperature:	$\leq$ 190 ^{o}F
Cylinder Curing:	Steam or moist—same as curing of the girders
Cylinder size:	4x8 in
Cylinder Capping Procedure:	Neoprene caps with a durometer hardness of 70 in steel rings
Cylinder Testing Method:	AASHTO T 22
Frequency of Testing:	One set of cylinders from each end of the bed
Other QA/QC Requirements:	—
Deck Construction	
Curing:	Moist (wet burlap covered with plastic sheeting for 7 days) Curing compound applied after removal of plastic sheeting and burlap
Cylinder Curing:	Moist
Cylinder Size:	4x8 in
Flexural Strength:	Not specified
Other QA/QC Requirements:	Air content, slump, and concrete temperature to be measured

5. CONCRETE MATERIALS

A. Approved Concrete Mix Proportions

	Girders	Substructure	Deck
Cement Brand:	Not available	Not available	Not available
Cement Type:	I	II	II
Cement Composition:	Not available	Not available	Not available
Cement Fineness:	Not available	Not available	Not available
Cement Quantity:	752 lb/yd^3	353 lb/yd^3	329 lb/yd^3
GGBFS Brand:	—	Not available	Not available
GGBFS Quantity:	—	235 lb/yd^3	329 lb/yd^3
Fly Ash Brand:	—	—	—
Fly Ash Type:	—	—	—
Fly Ash Quantity:	—	—	—
Silica Fume Brand:	Not available	—	—
Silica Fume Quantity:	55 lb/yd^3	—	—
Fine Aggregate Type:	Crushed limestone	Natural sand	Natural sand
Fine Aggregate FM:	3.00	2.80	2.80
Fine Aggregate SG:	2.75	2.63	2.63
Fine Aggregate Quantity:	1425 lb/yd^3	1254 lb/yd^3	1173 lb/yd^3
Coarse Aggregate, Max. Size:	3/4 in	1 in	1 in
Coarse Aggregate Type:	No. 67 limestone	No. 57 arch marble	No. 57 arch marble
Coarse Aggregate SG:	2.76	2.73	2.73
Coarse Aggregate Quantity:	1675 lb/yd^3	1773 lb/yd^3	1773 lb/yd^3
Water:	255 lb/yd^3	259 lb/yd^3	263 lb/yd^3
Water Reducer Brand:	Cormix P7-R	Polyheed 997	Polyheed 997
Water Reducer Type:	D	A and F	A and F
Water Reducer Quantity:	24 to 30 fl oz/yd^3	47 to 59 fl oz/yd^3	66 fl oz/yd^3
High-Range Water-Reducer Brand:	Melmet 50	Rheobuild 1000	Rheobuild 1000
High-Range Water-Reducer Type:	A and F	A and F	A and F
High-Range Water-Reducer Quantity:	202 fl oz/yd^3	0 to 47 fl oz/yd^3	13 to 20 fl oz/yd^3
Retarder Brand:	Cormix P7-R	—	—
Retarder Type:	D	—	—
Retarder Quantity:	24 to 30 fl oz/yd^3	—	—
Corrosion Inhibitor Brand:	—	—	—
Corrosion Inhibitor Type:	—	—	—
Corrosion Inhibitor Quantity:	—	—	—
Air Entrainment Brand:	Airtite 60	Micro-Air	Micro-Air
Air Entrainment Type:	Neutralized vinsol resin	Synthetic surfactant mixture	Synthetic surfactant mixture
Air Entrainment Quantity:	3 to 7 fl oz/yd^3	3 to 5 fl oz/yd^3	8.5 fl oz/yd^3
Water/Cementitious Materials Ratio:	0.32	0.44	0.40

B. Measured Properties of Approved Mix

	Girders	Deck
Slump:	5.8 in	3.5 in
Air Content:	4.2 in	5.5 in
Unit Weight:	—	—
Compressive Strength:	8470 psi at 28 days	6430 psi at 28 days
Chloride Permeability: (AASHTO T 277)	—	1109 coulombs at 28 days

6. CONCRETE MATERIAL PROPERTIES

A. Measured Properties from QC Tests of Production Concrete for Girders

Cement Composition:	Not available	
Actual Curing Procedure for Girders:	Nine were steam cured Eleven were moist cured over the weekend	
	Steam Cured	Moist Cured
Average Slump:	6.8 in	5.6 in
Maximum Girder Temperature:	166 ^{o}F	—
Average Air Content:	5.9%	5.9%
Unit Weight:	—	—

Average Compressive Strength:

Age, days	Steam Cured
0.75	7340 psi
28	9060 psi

Age, days	Moist Cured
3	7,820 psi
28	11,490 psi

Curing Procedure for Cylinders: Steam or moist—same as the curing of the girders

B. Measured Properties from QC Tests of Production Concrete for Substructure and Deck

Cement Composition:	Not available	
Actual Curing Procedure for Deck:	Wet burlap, plastic cover, insulating blanket, and external heat for seven days	
	Substructure	Deck (5)
Average Slump:	4.9 in	5.7 in
Maximum Temperature:	—	—
Average Air Content:	5.8%	7.0%
Unit Weight:	—	—
Average Compressive Strength:	6320 psi at 28 days	6600 psi at 28 days
Curing Procedure for Cylinders:	—	—

(5) Concrete samples taken before pumping.

C. Measured Properties from Research Tests of Production Concrete for Girders

Air Content, Slump, and Concrete Temperature:

Batch No.	1	2	3	4
Curing	Steam		Moist	
Air, %	4.5	6.5	6.2	5.7
Slump, in	6.3	7.0	5.8	6.8
Concrete Temp. at Time of Placement, ^oF	91	89	92	91

Compressive Strength, Modulus of Elasticity,
Flexural Strength, Splitting Tensile Strength,
Chloride Permeability, and Shrinkage:

Test	Specimen			Girder Batch No. (6)			
	Size	Age	No.	1	2	3	4
Compressive Strength (7), psi	4x8 in	1 d (8)	2	8430	8230	8870 (9)	9030 (9)
		1 d	3	8170	7840	7830 (9)	7830 (9)
		28 d	3	9850	9690	12,120	11,960
		56 d	3	9890	9860	12,120	12,310
		1 yr	3	9840	9720	11,830	11,730
Modulus of Elasticity (10), ksi	4x8 in	28 d	3	5980	5850	6210	6220
		56 d	—	5960	6350	6660	6420
Flexural Strength (11), psi	3x3x 11-1/4 in	28 d	3	970	865	1005	990
Splitting Tensile Strength (12), psi	4x8 in	28 d	3	760	825	950	910
Chloride Permeability(13), coulombs	2x4 in	28 d	2	254	290	178	188
		1 yr	2	280	300	119	184
Shrinkage (14), %	3x3x 11-1/4 in	1 yr	3	0.029	0.031	0.048	0.050

(6) Batches 1 and 2 were steam cured. Batches 3 and 4 were moist cured.
(7) AASHTO T 22 with neoprene pads in steel end caps.
(8) Match cured until release and then tested. All other specimens stored alongside beams initially and stored outdoors thereafter.
(9) At 3 days.
(10) ASTM C 469.
(11) AASHTO T 97 (ASTM C 78).
(12) AASHTO T 198 (ASTM C 496).
(13) AASHTO T 277 (ASTM C 1202). Cured one week at 73 ^oF and three weeks at 100 ^oF.
(14) AASHTO T 160 (ASTM C 157). Shrinkage specimens were air cured outside for 4 months and then kept indoors.

D. Measured Properties from Research Tests of Production Concrete for Substructure

Air Content, Slump, Concrete Temperature, and Air Temperature:

Batch No.	1	2	3
Air, %	5.4	5.2	4.8
Slump, in	4.5	4.5	3.8
Concrete Temp. at Time of Placement, ^oF	72	90	90
Air Temp., ^oF	67	92	92

Compressive Strength, Modulus of Elasticity, Flexural Strength, Splitting Tensile Strength, Chloride Permeability, and Shrinkage:

Test	Specimen			Substructure Batch No.		
	Size	Age	No.	1	2	3
Compressive Strength (15), psi	4x8 in	1 d	—	2120	1940	1480
		7 d	3	4190	4430	3900
		28 d	3	5820	6160	5800
		1 yr	3	6870	7320	6730
Modulus of Elasticity (16), ksi	4x8 in	28 d	—	—	4830	4730
		1 yr	—	5190	—	—
Flexural Strength (17), psi	3x3x 11-1/4 in	28 d	3	835	815	740
Splitting Tensile Strength (18), psi	4x8 in	28 d	3	590	625	575
Chloride Permeability (19), coulombs	2x4 in	28 d (20)	2	1323	883	1076
		28 d	—	1831	1347	1670
		1 yr	—	815	710	904
Shrinkage (21), %	3x3x 11-1/4 in	64 wk	3	—	0.51	0.50

(15) AASHTO T 22 with neoprene pads in steel end caps.
(16) ASTM C 469.
(17) AASHTO T 97 (ASTM C 78).
(18) AASHTO T 198 (ASTM C 496).
(19) AASHTO T 277 (ASTM C 1202).
(20) Cured one week at 73 ^oF and three weeks at 100 ^oF.
(21) AASHTO T 160 (ASTM C 157). Moist cured for 28 days, then air dried.

E. Measured Properties from Research Tests of Production Concrete for Deck

Air Content, Slump, Concrete Temperature,
and Air Temperature:

Batch No.	1	2	3	4
Air, %	—	6.4	3.4	6
Slump, in	5.5	4.8	4.3	4.3
Concrete Temp. at Time of Placement, °F	53	53	61	61
Air Temp., °F	56	56	67	67

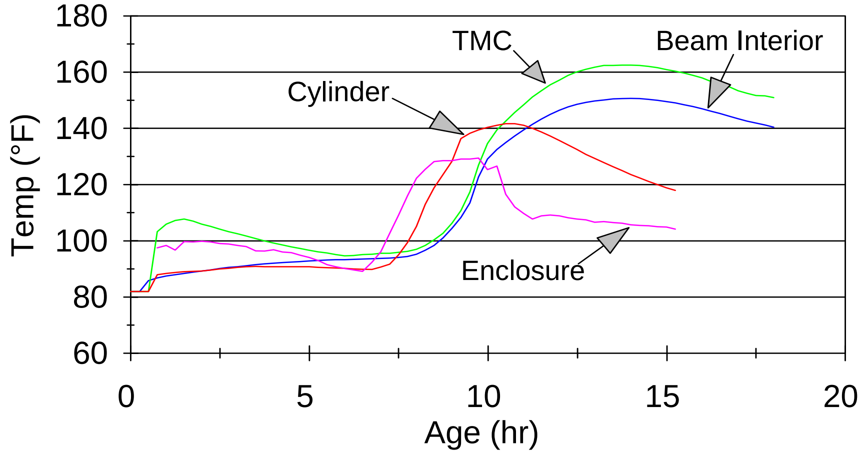
Compressive Strength, Modulus of Elasticity,
Flexural Strength, Splitting Tensile Strength,
Chloride Permeability, and Shrinkage:

Test	Specimen			Deck Batch No.			
	Size	Age	No.	1	2	3	4
Compressive Strength (22), psi	4x8 in	1 d	—	590	420	1730 (23)	1660 (23)
		7 d	3	5820	5440	5400	4890
		28 d	3	8400	8100	9050	9290
		1 yr	3	9510	9280	10,680	10,810
Modulus of Elasticity (24), ksi	4x8 in	1 yr	3	5590	5470	6320	6120
Flexural Strength (25), psi	3x3x 11-1/4 in	28 d	3	870	830	1040	1000
Splitting Tensile Strength (26), psi	4x8 in	28 d	3	765	685	750	750
Chloride Permeability (27), coulombs	2x4 in	28 d (28)	2	696	773	743	898
		28 d	—	1428	1405	1256	1677
		1 yr	—	705	674	602	782
Shrinkage (29), %	3x3 11-1/4 in	64 wk	3	0.059	0.057	0.045	0.048

(22) AASHTO T 22 with neoprene pads in steel end caps.
(23) At 3 days.
(24) ASTM C 469.
(25) AASHTO T 97 (ASTM C 78).
(26) AASHTO T 198 (ASTM C 496).
(27) AASHTO T 277 (ASTM C 1202).
(28) Cured one week at 73 °F and three weeks at 100 °F.
(29) AASHTO T 160 (ASTM C 157). Moist cured for 28 days, then air dried.

7. OTHER RESEARCH DATA

Curing Temperatures (30):



(30) TMC is the temperature of a match-cured cylinder.
Cylinder temperature is that of a cylinder stored next to the girder under the enclosure.
Enclosure temperature is that under the enclosure covering the girder.

Load Test: A load test was conducted on one beam. The purpose of the test was to determine the amount of residual deflection in the beam after removal of a maximum load equal to 95 percent of the calculated load to cause a flexural crack. The result was reported in terms of percentage of the midspan deflection recovery to the deflection at the maximum load. The beam was considered to be adequate if a recovery of 90 percent or greater was achieved. The instantaneous recovery was 97.9 percent. At 30 minutes after removing the load, the recovery was 100 percent. No cracks were seen in the beam.

8. OTHER RELATED RESEARCH

Before initiation of the Brookneal project, an experimental project was conducted to support the design of high-strength, low permeability beams with 0.6-in-diameter strands. Four prestressed concrete AASHTO Type II beams each containing ten 0.6-in-diameter strands at 2-in center-to-center spacing, two on top and eight across the bottom, were fabricated at a prestressing plant and tested to failure at the FHWA Structures Laboratory. Two of the beams were prepared with concrete to develop a compressive strength of 10,000 psi and the other two with 12,000-psi compressive strength concrete. The beams were steam cured to obtain 70 percent of the compressive strength within 24 hours.

Trial batches were prepared at the plant and in the laboratory before the preparation of actual field concretes for the test beams. Concrete tests showed that high-strength air-entrained concretes with 28-day strengths exceeding 10,000 psi and a minimum release strength of 70 percent of the 28-day strengths could be produced with a water-cementitious materials ratio (w/cm) of about 0.30 or less. To achieve such low w/cm required high amounts of cementitious material, proper selection of aggregates, and high dosages of HRWRA. To achieve high early strengths, proper temperature management was needed. With low curing temperatures, it is difficult to achieve high early strengths, but higher ultimate strengths can be achieved. Optimum temperature for both the early and ultimate strengths could only be determined by trial batching and testing.

The mixture proportions for the test beams are given in Table 1. A fixed amount of coarse aggregate, 1,800 lb/yd^3, was used in these concretes. In two of the beams, the temperature within the beam was continuously monitored by thermocouples embedded prior to casting. During steam curing, a temperature of 160 ^{o}F was planned within the enclosure. However, the enclosure temperature inadvertently approached 185 ^{o}F, which resulted in concrete temperatures of 219 ^{o}F and 208 ^{o}F in two beams. Some of the test specimens stored in the recesses of the forms exhibited visual cracks attributed to high heat. These specimens exhibited high variability in strength and some did not meet the strength requirements due to heat-related damage. However, some of the specimens had strengths above the requirements.

Table 1. Mixture proportions for the test beams.

Constituents	Concrete Compressive Strength, psi	
	12,000	10,000
Portland Cement, lb/yd^3	750	650
Type of Cement	II M, finely ground	
Slag, lb/yd^3	300	300
Water/Cementitious Materials Ratio	0.27, 0.28	0.31, 0.32
Coarse Aggregate, lb/yd^3	1800	
Coarse Aggregate Max. Size, in	1/2 in	
Coarse Aggregate Type	No. 78, granite	
Coarse Aggregate – Specific Gravity	2.98	
Fine Aggregate, lb/yd^3	977	1086
Fine Aggregate – Type	Siliceous sand	
Fine Aggregate – Specific Gravity	2.60	
Fine Aggregate – Fineness Modulus	2.90	

In addition to temperature monitoring, the beams were instrumented with brass studs, spaced at intervals of 4 in on the outside surface of the beams along the path of both the bottom strands and the draped strands. Measurements with a Whittemore mechanical strain gage were taken before and just after detensioning, as well as at one day, 7 days, 14 days, and 28 days from time of placement of the concrete. The difference between the initial reading and the readings after detensioning, normalized with respect to the initial readings, yields a strain profile along the face of the girder at the location of the brass studs. Ideally, this strain profile reaches a plateau, indicating that the transfer of prestressing force from the strands to the concrete has occurred. The embedment length can then be determined by conducting a flexural test on the beam.

Unfortunately, operator error in the initial readings and damaged studs during demolding resulted in significant scatter in the data and a reasonable estimate of the transfer length could not be made. Thus, the experimental determination of development lengths was cancelled and testing was limited to the determination of cracking strength and ultimate strength. Also, plans for the use of 0.6-in-diameter strands for the girders in the first three bridges were discontinued.

The beams were tested to determine the maximum load carrying capacity under a concentrated load at midspan. The calculated maximum design concentrated loads at midspan were determined to be 148 and 144 kips, based on the design moment capacity as predicted by equation 9-13 of the *AASHTO Standard Specifications*. The calculated maximum design concentrated loads at midspan to cause first crack were 83 and 85 kips for the 10,000-and 12,000-psi beam designs. The results of the load testing are shown in Table 2. The lowest load to cause first crack was observed to be 90 kips in Beam 1 designed for 12,000-psi compressive strength. This beam had the high internal temperatures exceeding boiling. All flexural failures were due to concrete crushing in the outermost fibers of the top flange. The prestressed beams with 0.6-in-diameter strands had satisfactory concrete strengths (exceeding 10,000 psi), and performed as intended under the loading condition and did not reflect the high variability and lower-than-desired strengths observed in the test specimens damaged by heat.

Table 2. Results of load testing - Test Program 1.

Test Beam	Concrete Design Strength, psi	Cracking Load, kip		Ultimate Load, kip	
		Predicted	Measured	Predicted	Measured
1	12,000	85	90	148	162
2	12,000	85	100	148	175
3	10,000	83	105	144	177
4	10,000	83	100	144	165

9. SOURCES OF DATA

Ozyildirim, C. and Gomez, J., "HPC in Virginia's Bridge Structures," *Symposium Proceedings, PCI/ FHWA/fib International Symposium on High Performance Concrete*, Orlando, FL, Precast/Prestressed Concrete Institute, Chicago, IL, 2000, pp. 741-750.

Ozyildirim, C., “HPC Bridge Decks in Virginia," *ACI Concrete International*, Vol. 21, No. 2, February 1999, pp. 59-60.

SHRP High Performance Concrete Bridge Showcase Notebook, Richmond, VA, June 24-26, 1997.

Ozyildirim, C. and Gomez, J., "Virginia's Bridge Structures with High Performance Concrete," *Symposium Proceedings, PCI/FHWA International Symposium on High Performance Concrete*, New Orleans, LA,, Precast/Prestressed Concrete Institute, Chicago, IL, 1997, pp. 681-690.

Ozyildirim, C. and Gomez, J., “High Performance Concrete In Bridge Structures In Virginia," *ASCE Proceedings: Materials for the Millennium, American Society of Civil Engineers*, New York, NY, November 1996, pp. 1357-1366.

Ozyildirim, C., Gomez, J., and Elnahal, M., “High Performance Concrete Applications In Bridge Structures In Virginia," *ASCE Proceedings: Worldwide Advances in Structural Concrete and Masonry*, American Society of Civil Engineers, New York, NY, 1996, pp. 153-163.

H. Celik Ozyildirim, Virginia Transportation Research Council, Charlottesville, VA.

10. DRAWINGS

Not provided for this bridge.

11. HPC SPECIFICATIONS

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
LOW PERMEABILITY CONCRETES

August 29, 1994
Rev: May 21, 1996c

SECTION 217 of the Specifications is amended as follows:

Section 217.02(a) is replaced with the following:

Cement shall conform to the requirements of Section 214 and shall be Type II with a maximum alkali content of 0.40% or Type I-P, unless otherwise permitted herein or otherwise specified in the contract. Fly ash or granulated iron blast-furnace slag shall not be added to concrete when Type I-P cement is used. Fly ash, granulated iron blast-furnace slag, silica fume, or other approved mineral admixtures shall be used with Types I, II (if above 0.40% alkali content) or III cements as specified herein.

Types I, II, and III cements may be used with latex modified portland cement concrete, however latex will not be permitted in Class A5 concrete.

Granulated iron blast-furnace slag shall replace from 35% to 50% by weight of the design cement content.

Other mineral admixtures shall be used in accordance with the requirements shown on the approved list of mineral admixtures.

Section 217.02 is amended to replace (h) and (i) with the following:

(h) **Fly ash** shall conform to the requirements of Section 241. Class F fly ash shall be between 20% and 25% by mass of the cementitious material. However, no more than 15% of the portland cement of a standard mixture shall be replaced.

(i) **Granulated iron blast-furnace slag** shall conform to the requirements of Section 215.

Section 217.02 is amended to add the following:

(k) **Silica fume** shall conform to the requirements of AASHTO M307 or ASTM C1240. Silica fume shall replace between 7% and 10% by mass of the cementitious material. Only silica fume at the rate of 3% to 7% may be added to all combinations to reduce the early permeability after the approval of the Engineer.

Section 217.08 is amended to add the following:

(c) **Quality Assurance for Low Permeability Concrete (for Concrete in Bridges Only):**

General:

At least two trial batches (using job materials) with permissible combination of cementitious materials shall be prepared, and test specimens shall be cast by the contractor and tested by the Department for permeability and strength at least a month before the field application. The permeability samples shall be cylindrical specimens with a 100-mm (4-in) diameter and at least 100-mm (4-in) in length. They shall be moist cured as the strength cylinders for acceptance except that the last 3 weeks of cure shall be at 38 °C ± 6 °C (100 °F ± 10 °F). Cylinders shall be tested at 28 days in accordance with AASHTO T 277 or ASTM C 1202. The test value shall be the result of the average values of tests on two specimens from each batch. Permeability values obtained from trial batches shall be 500 coulombs below the maximum values specified in Table II-17.

Acceptance Tests:

A quality assurance and acceptance procedure that provides for periodic tests of the field concrete for permeability using AASHTO T 277, shall be established. This should include provisions for testing frequency; the range of coulomb values for which full or partial payments would be made; and the values that would require corrective measures to be taken (or rejection of the concrete) should be stated. The following are quality assurance procedures for field evaluations.

A lot shall be a day's production of concrete for the job and shall be used for statistical acceptance procedure for bridge concrete. For each set of cylinders made for compressive strength tests, two additional cylinders shall be made for the permeability test.

For all classes of concrete, initially one set of permeability cylinders shall be tested for each lot in accordance with AASHTO T 277. If the average coulomb value for this test is less than the coulomb value shown in Table II-17, the lot will be accepted at the full bid price.

If the average test result exceeds the coulomb value in Table II-17, payment for the concrete in that element (in-place cost) shall be reduced 0.02 percent for each coulomb above the coulomb value in Table II-17, however, the reduction in price will not exceed 20% of the bid price of the concrete. Concrete with a coulomb value that exceeds the maximum required in Table II-17 by 1000 coulomb will be rejected. However, bridge deck with the coulomb value exceeding the maximum required by over 1000 coulomb may be accepted by the Engineer at 80% of the bid price if it has the required strength and meets other specification requirements, and the contractor applies, at his own expense, an approved epoxy concrete overlay to the top of the deck. In such case deck grooving will not be required. The adjustment to the roadway grade shall be made as required by the Engineer at the Contractor's expense.

Similarly, concrete in abutments and pier caps with coulomb value exceeding the maximum required in Table II-17, by more than 1000 coulomb may be accepted at 80% of the bid price if it has the required strength and meets other specification requirements, and the contractor applies at his own expense, an approved epoxy, conforming to Type EP-3B and EP-3T (of Section 243.02), on top of the pier cap or abutment seat.

The reduction in the bid prices mentioned above shall be applied to the total volume of concrete in bridge members (deck slab of a single span, deck slab of a group of continuous spans, pier or abutment) for which any portion of the concrete in the member did not meet the permeability test requirements.

Section 404.03(k) Curing Concrete is amended to add the following:

> **Section 404.03(k)1. Curing Bridge Deck and Overlay Concrete:** Bridge deck and overlay concrete, including latex modified concrete, shall be moist cured for a minimum of 7 days and until 70% **f′c** is reached. Moist curing shall be maintained by wet burlap (keep wet) for the duration of the curing and covered with plastic sheeting. Immediately after screeding and until the application of wet burlap and white plastic sheeting (opaque and transparent sheeting may be used when the air temperature falls below 10 °C (50 °F)), no surface of the freshly placed concrete shall be allowed to dry. During moist curing, the concrete temperature shall be maintained above 10 °C (50 °F) at the outer most surfaces of the concrete mass. Immediately after removing the burlap and plastic sheeting (except for latex-modified concrete), white pigmented curing compound shall be applied while the surface is damp but has no free water standing on it. The application rate shall be 2.4 - 3.6 square meters per liter (100 to 150 sq.ft./gal.).

Section 404.03(l) 1. Weather is amended to replace the 4th paragraph with the following:

Protection shall be provided to prevent rapid drying of concrete as a result of low humidity, high wind, high atmospheric temperatures, or combinations thereof. For bridge deck and overlay concretes, fogging with pressure sprayers sufficient to maintain a moist surface shall be required. The protective measures taken shall maintain an evaporation rate at or below 0.5 kg/sq m/hr (0.10 lb/sq ft/hr) for bridge deck concrete and 0.3 kg/sq m/hr (0.05 lb/sq ft/hr) for concrete overlays. The Contractor shall determine the evaporation rate and take appropriate action. Other preventative measures described in ACI 308 can also be used in addition to fogging. Evaporation retardant films may be applied in a fine mist immediately after screeding to ensure that the surface remains wet until covered. If such materials are used, they shall not be intermixed with the surface mortar. Placement of concrete shall be regulated at a rate such that the finishing operations are able to be completed and the wet burlap and polyethylene sheeting are placed prior to any drying of the concrete.

Section 404.03 is amended to add the following:

(n) **Defective Concrete:** All defective or damaged concrete which occurs prior to the final acceptance of the work shall be repaired or replaced at the Contractor's expense. Defects shall include, but not be limited to, cracking, tearing, and damage or other imperfections.

All visible cracks and construction joints in bridge deck concretes shall be sealed by the contractor using an approved polymer. Concrete shall be at least 28 days old and dry before the application of the polymer. Concrete shall be grooved after the application of the polymer.

Section 404.04 is amended to add the following:

Consolidation: In deck placements, internal vibrators and screeds with vibrating element shall be used. The minimum frequency of the vibrating element shall be 3,000 vibrations per minute. Internal vibration shall be required along the transverse and longitudinal edges and joints, and where the thickness of concrete exceeds 75 mm (3 in).

Section 405.02(a) is amended to add the following:

Prestressed concrete in structures other than those over tidal water shall contain 15 l/m3 (3 gal/yd3) of calcium nitrite only if the coulomb value of the concrete exceeds 1500. Prestressed concrete for structures over tidal water shall contain either 25l/m3 (5.0 gal/yd3) of calcium nitrite if the coulomb value of concrete exceeds 1,500 or 10 l/m3 (2.0 gal/yd3) of calcium nitrite if the coulomb value of concrete is 1,500 or less.

Section 405.05(c) is amended to replace the last sentence with the following:

Both internal vibrators and external form vibrators shall be used for concrete with strength equal or exceeding 55 MPa (8000 psi). The use of external vibration for other concrete will be at the option of the Contractor with approval of the Engineer. Improper placing and vibrating may be cause for rejection.

Section 405.05(f)4. is completely replaced by the following:

> The temperature rise in the curing enclosure shall be uniform, with a rate rise of not more than 27 °C (80°F) per hour. Concrete shall be cured at a steam temperature of not more than 82 °C (180°F), with the steam temperature uniform throughout the curing enclosure, and with a variation of not more than –7 °C (20°F). Maximum concrete temperature during the curing cycle shall be 88 °C (190°F). Approved recording thermometers shall be placed so that temperatures can be recorded at a minimum of two locations spaced at or near the third of the length in each curing enclosure and at least one sensor shall measure the temperature in the concrete.

TABLE II-17 Requirements for Hydraulic Cement Concrete of the Specifications is replaced by the following:

TABLE II-17
Requirements for Hydraulic Cement Concrete
(English Units)

Class of Concrete	Design Min. Laboratory Compressive Strength at 28 Days (f'c) (psi)	Design Max. Laboratory Permeability at 28 Days (Coulombs)	Nominal Max. Aggregate Size (in)	Min. Cementitious Content (lb/cu yd)	Max. Water/Cementitious Mat. (lb Water/lb Cement)	Consistency (in of slump)	Air Content (%)[1]
A5 Prestressed and other special designs[2]	5,000 or as specified on the plans	1,500	1	635	0.40	0-4	4 1/2 +/- 1 1/2
A4.5	4,500	2,500	1	635	0.45	2-4	6 1/2 +/- 1 1/2
A4 General	4,000	2,500	1	635	0.45	2-4	6 1/2 +/- 1 1/2
A4 Post & rails[3]	4,000	2,500	0.5	635	0.45	2-5	7 +/- 2
A3 General	3,000	3,500	1	588	0.45	1-5	6 +/- 2
A3 Paving	3,000	3,500	1	564	0.49	0-3	6 +/- 2
B2 Massive or lightly re-inforced	2,200	N.A.	1	494	0.58	0-4	4 +/- 2
C1 Massive Un-reinforced	1,500	N.A.	1	423	0.71	0-3	4 +/- 2
T3 Tremie seal	3,000	N.A.	1	635	0.49	3-6	4 +/- 2
Latex hydraulic cement concrete overlay[4]	3,500	1,500	0.5	658	0.40	4-6	5 +/- 2
Silica fume concrete overlay	5,000	1,500	0.5	658[5]	0.40	4-7	6 +/- 2

[1] When a high-range water reducer is used, the target air content shall be increased 1% and the slump shall not exceed 7 inches.

[2] When Class A5 concrete is used as the finishing bridge deck riding surface, or when it is to be covered with asphalt concrete with or without waterproofing, the air content shall be 5 1/2 +/- 1 1/2%.

[3] When necessary for ease in placement, aggregate No. 7 shall be used in concrete posts, rails, and other thin sections above the top of bridge deck slabs.

[4] The latex modifier content shall be 3.5 gallons per bag of cement. Slump shall be measured approximately 4.5 minutes after discharge from the mixer.

[5] Minimum 7% silica fume replacement by weight of the total cementitious material.

Note: Contractor may substitute a higher class of concrete for that specified at his expense.

TABLE II-17
Requirements for Hydraulic Cement Concrete
(Metric units)

Class of Concrete	Design Min. Laboratory Compressive Strength at 28 Days (f'c) (MPa)	Design Max. Laboratory Permeability at 28 Days (Coulombs)	Nominal Max. Aggregate Size (mm)	Min. Cementitious Content (kg/cu m)	Max. Water/Cementitious Mat. (kg Water/kg Cement)	Consistency (mm of slump)	Air Content (%)[1]
A35 Prestressed and other special designs[2]	35 or as specified on the plans	1,500	25	375	0.40	0-100	4 1/2 +/- 1 1/2
A30 General	30	2,500	25	375	0.45	50-100	6 1/2 +/- 1 1/2
A30 Post & rails[3]	30	2,500	13	375	0.45	50-125	7 +/- 2
A25 General	25	3,500	25	350	0.45	50-125	6 +/- 2
A25 Paving	25	3,500	25	335	0.49	0-75	6 +/- 2
B20 Massive or lightly re-inforced	20	N.A.	25	295	0.58	0-100	4 +/- 2
C15 Massive Un-reinforced	15	N.A.	25	250	0.71	0-75	4 +/- 2
T20 Tremie seal	20	N.A.	25	375	0.49	75-150	4 +/- 2
Latex hydraulic cement concrete overlay[4]	25	1,500	13	390	0.40	100-150	5 +/- 2
Silica fume concrete overlay	35	1,500	13	390[5]	0.40	100-175	6 +/- 2

[1] When a high-range water reducer is used, the target air content shall be increased 1% and the slump shall not exceed 175 millimeters.
[2] When Class A35 concrete is used as the finishing bridge deck riding surface, or when it is to be covered with asphalt concrete with or without waterproofing, the air content shall be 5 1/2 +/- 1 1/2%.
[3] When necessary for ease in placement, aggregate No. 7 shall be used in concrete posts, rails, and other thin sections above the top of bridge deck slabs.
[4] The latex modifier content shall be 13.25 liters per bag of cement. Slump shall be measured approximately 4.5 minutes after discharge from the mixer.
[5] Minimum 7% silica fume replacement by mass of the total cementitious material.
Note: Contractor may substitute a higher class of concrete for that specified at his expense.